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13. ABSTRACT

The salinity distribution in multiyear sea ice is dependent on the ice topography and cannot be adequately represented by a single average profile. The cores collected from areas beneath surface hummocks generally showed a systematic increase in salinity with depth from 0 $^0/_{00}$ at the surface to about 4 $^0/_{00}$ at the base. The cores collected from areas beneath surface depressions were much more saline and displayed large salinity fluctuations. Salinity observations from sea ice of varying thicknesses and ages collected at various arctic and subarctic locations revealed a strong correlation between the average salinity of the ice, $\overline{S}$, and the ice thickness, h. For salinity samples collected from cold sea ice at the end of the growth season, this relationship can be represented by two linear equations: $\overline{S} = 14.24 - 19.39h$ ($h \leq 0.4$ m); $\overline{S} = 7.88 - 1.59h$ ($h > 0.4$ m). It is suggested that the pronounced break in slope at 0.4 m is due to a change in the dominant brine drainage mechanism from brine expulsion to gravity drainage. A linear regression for the data collected during the melt season gives $\overline{S} = 1.58 + 0.18h$. An annual cyclic variation of the mean salinity probably exists for multiyear sea ice. The mean salinity should reach a maximum at the end of the growth season and a minimum at the end of the melt season.

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HANOVER, NEW HAMPSHIRE

PREFACE

This report was prepared by Gordon F.N. Cox, Dept. of Earth Sciences, Dartmouth College, and Dr. Wilford F. Weeks, Glaciologist, Snow and Ice Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. The research was supported by grant AG 344 from the Office of Polar Programs of the National Science Foundation.

The authors wish to thank S. Ackley, Dr. W.D. Hibler, III, A. Kovacs and Dr. R.O. Ramseier for their assistance during the field work. Dr. Hibler also gave advice on certain data-handling procedures. In addition, Dr. A. Assur, A. Kovacs and S. DenHartog made available a large number of unpublished salinity profiles. This work would have been impossible without the enthusiastic support of Dr. N. Untersteiner and the staff of the AIDJEX project office. Technical review of the manuscript was performed by Dr. Untersteiner and Dr. Hibler.

Manuscript received 24 May 1973

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SALINITY VARIATIONS IN SEA ICE

by

Gordon F.N. Cox and Wilford F. Weeks

INTRODUCTION

Despite the importance of the salinity prol.. . in determining the mechanical, thermal and electromagnetic properties of sea ice, few ice alinity data have been collected. Those data which are available have usually been obtained as an adjunct to some other study and have therefore not been systematically analyzed in their own right.

The salinity distribution in multiyear ice has b.. n particularly neglected. The prime reference on this subject is the study Schwarzacher (1959) perf..med during the drift of Ice Station Alpha in the Arctic Ocean. In this study he computed an average multiyear salinity profile based on the salinity profiles from 40 cores. This mean profile is commonly quoted in the literature and has served as a basis for a variety of calculations in which the profile properties of multiyear sea ice are important (Assur 1967, Untersteiner 1967, Weeks and Assur 1967, Maykut and Untersteiner 1971). However, his study does not encompass such variables as surface topography, internal structure, age and thickness, all of which must affect the multiyear salinity profile. Nor does it adequately describe the transition from a first-year to a multiyear ice salinity profile and the brine drainage mechanisms (Untersteiner 1967).

The present study was undertaken to supplement Schwarzacher's data and to determine the variation, if any, in multiyear ice salinity profiles with changes in ice surface topography. The results also led to an examination of the variation of the mean salinity of both first-year and multiyear ice with changes in ice thickness.

FIELD SITES AND PROCEDURES

Most of the multiyear ice salinity data used in this paper were collected during March and April 1972 from an area near the main AIDJEX camp, located in the Beaufort Sea at approximately 75°N, 148°W (Fig. 1). Here salinity cores were collected from beneath both melt hummocks and the adjacent depressions which presumably represent sites at which melt ponds were located during the summers. Care was taken to avoid pressure ridges and areas of deformed ice. Salinity samples from new ice were collected at daily intervals from a 3- × 3-m test pond cut in the thin ice of a refrozen lead. Continuous ice samples 7.6 cm in diameter were obtained with a CRREL corer attached to a power drill. Once the core was removed from the ice, it was quickly cut into 10-cm sections with a band saw and sealed in airtight 1-quart freezer containers. Very thin ice was cut in 2-cm sections. The salinity of the melted ice was then determined with a Beckman conductivity solubridge (± 0.1 ‰).

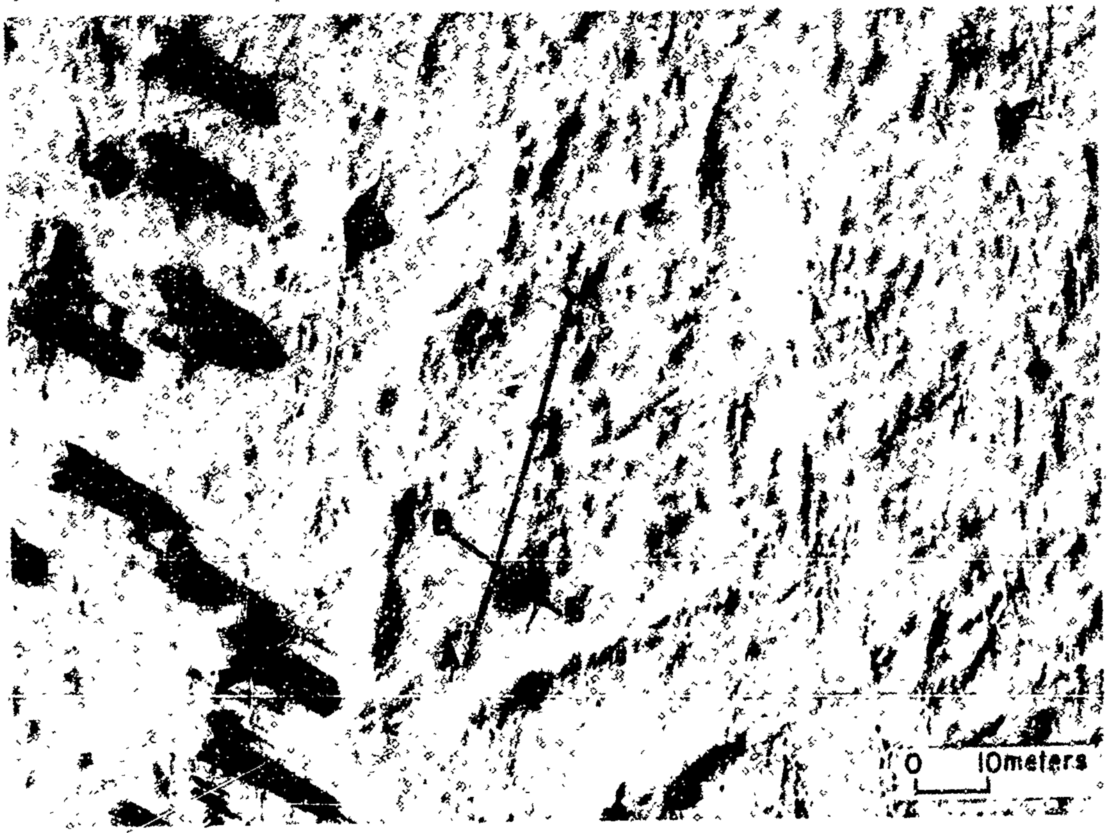

Figure 1. Sampling area near main AIDJEX camp. A-A' and B-B' are approximate cross-section lines.

Because of cold air (–25°C) and low ice temperatures during sampling, there was very little brine drainage. No large brine pockets and only a few brine drainage tubes were observed, so that the salinity profiles should be representative. Approximate ice temperatures were obtained from some cores as soon as they were removed from the ice sheet by inserting a thermistor into the core center.

These results were combined with additional salinity observations collected by investigators on field projects on the Labrador coast, the Bering and Beaufort Seas, and Viscount Melville Sound. The sampling techniques were similar to those used in this study, except that salinities in the Hopedale, Labrador, study were determined by hydrometer.

RESULTS

Salinity profiles of the melt hummocks differed significantly from those of the depressions. The hummocks showed a systematic increase in salinity with depth from 0 ‰ at the surface to about 4 ‰ at the base (Fig. 2). The depressions showed large, irregular salinity fluctuations (Fig. 3, 4), and the upper layers in these cores showed salinity values up to 6.3 ‰. Because of the low ambient temperatures, it was impossible to avoid cooling of the core upon removal from the ice sheet. To compensate for this effect, only the maximum temperature values were considered when interpolating the temperature profiles shown in Figures 2, 3 and 4. The brine volumes shown were calculated by using the equation derived by Frankenstein and Garner (1967) based on Assur's (1960) brine volume table. Figure 5 illustrates the ice topography, ice thickness, and relative position of some of the salinity cores. A tabulation of the AIDJEX multiyear ice core data is presented in Appendix A.

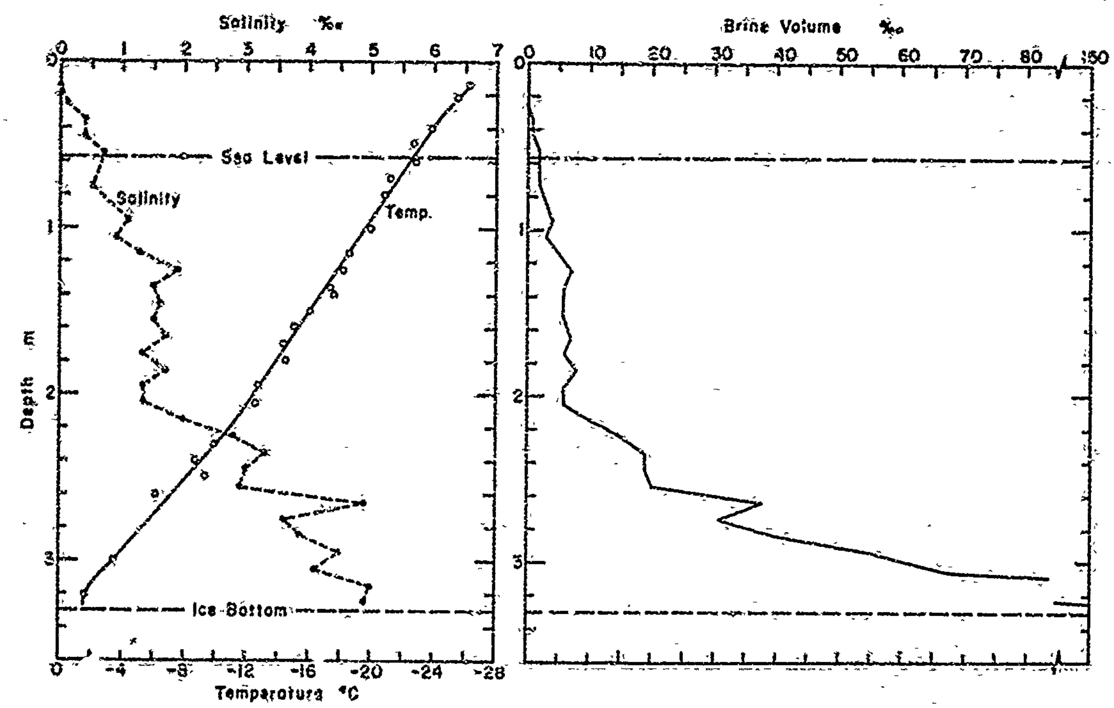

Figure 2. Typical hummock salinity profile (profile S1) with temperature and brine volume profiles.

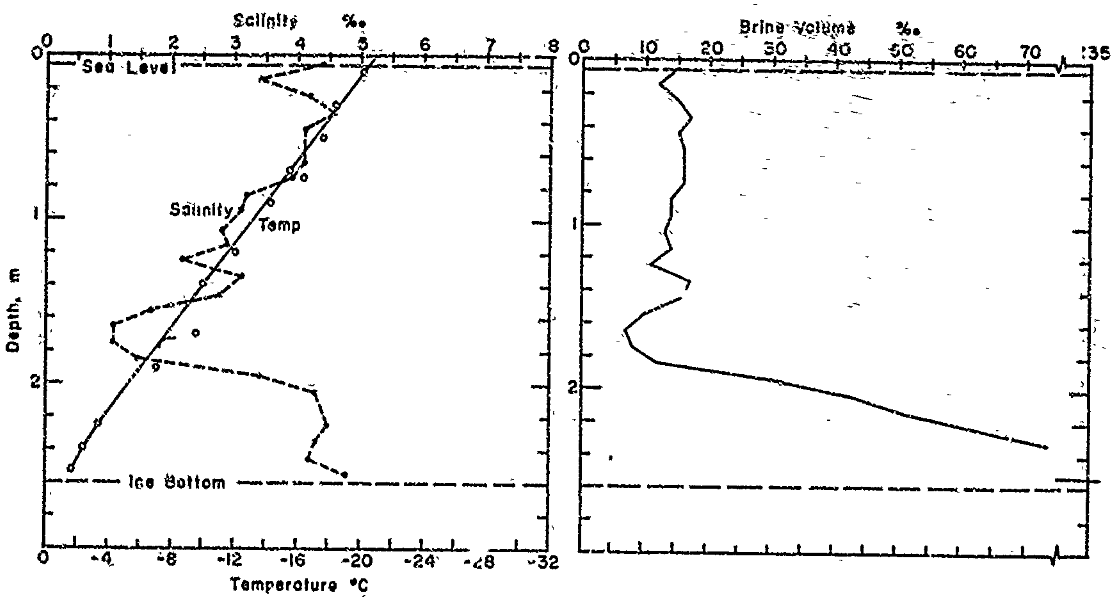

Figure 3. Depression salinity profile S5b with temperature and brine volume profiles.

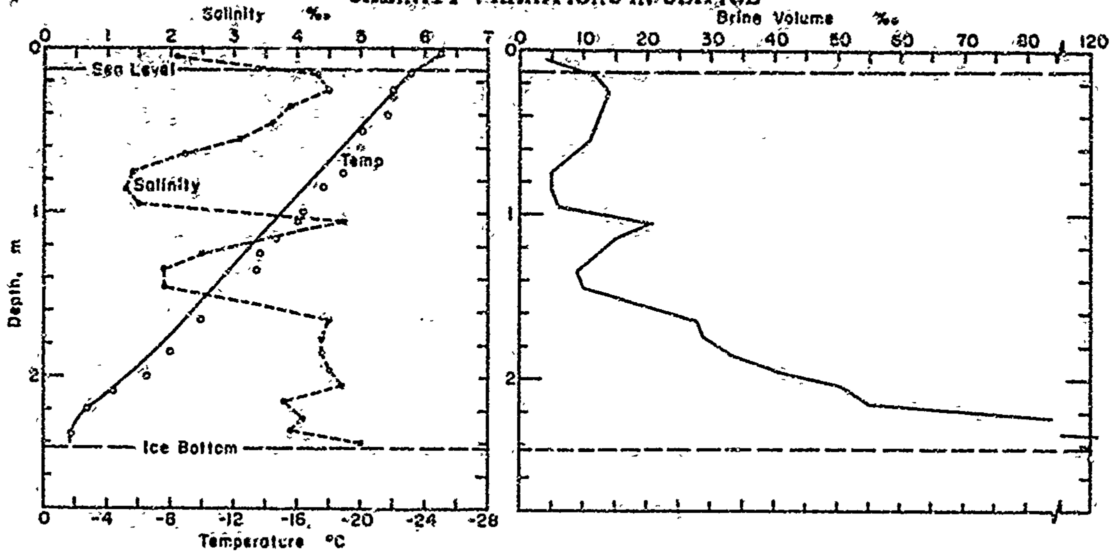

Figure 4. Depression salinity profile S2 with temperature and brine volume profile.

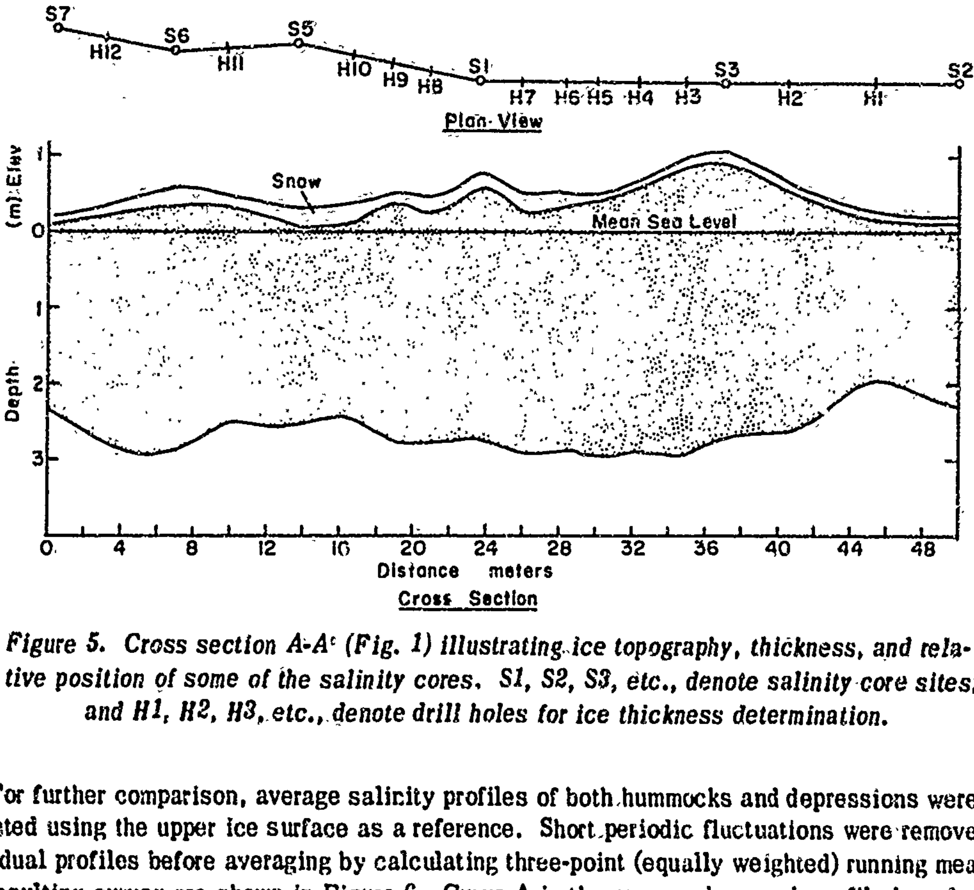

Figure 5. Cross section A-A' (Fig. 1) illustrating ice topography, thickness, and relative position of some of the salinity cores. S1, S2, S3, etc., denote salinity core sites; and H1, H2, H3, etc., denote drill holes for ice thickness determination.

For further comparison, average salinity profiles of both hummocks and depressions were computed using the upper ice surface as a reference. Short periodic fluctuations were removed from individual profiles before averaging by calculating three-point (equally weighted) running means. The resulting curves are shown in Figure 6. Curve A is the average hummock profile based on seven cores, and curve B is the average depression profile based on ten cores. Curve C is the average multiyear sea ice salinity profile determined by Schwarzacher (1959). The lower portions of the curves are the least reliable, because most profiles were not of equal length. Curve B is not truly representative, in that the irregular salinity fluctuations typical of individual depression profiles have been removed by averaging all the profiles. However, it is clear that the average salinity of the depression profile (3.9 ‰) is much greater than that of the hummock profile (2.6 ‰).

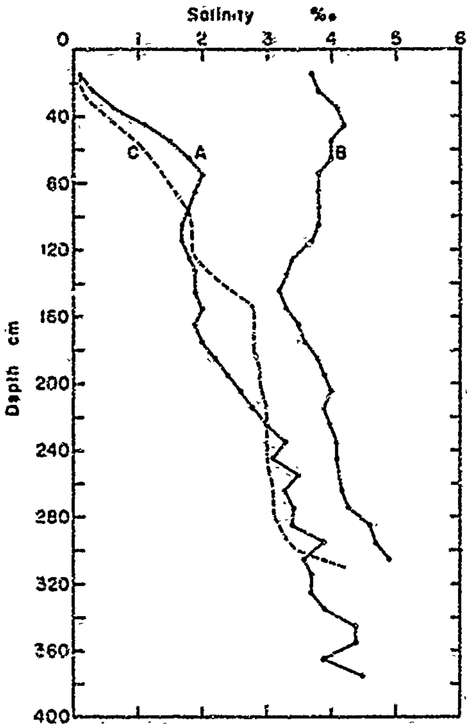

Figure 6. Average salinity profiles. Curves A and B are the average hummock and depression salinity profiles, respectively. Curve C is the multiyear ice average salinity profile determined by Schwarzacher (1959).

Once it was determined that these differences were consistent, a depression-hummock-depression section was sampled in detail. To study the variation in salinity, cores were taken at 1-m intervals. The results (Fig. 7) illustrate several features typical of hummock and depression profiles. The salt content is much lower in the upper portion of the hummock than in the adjacent depressions. The transition from high to low salinity takes place laterally within 2 m. Also, the salinity of the ice beneath the depressions is greater and more variable. Distinct distribution patterns are evident. The salinity in the center of the ice is distributed irregularly, with isolated high and low salinity pockets; the top and bottom portions are stratified. The lower, more uniform portion of the ice is undoubtedly the growth of the previous winter. The salinity data for the 16 cores are presented in Appendix A, profiles D1-D16.

A strong correlation was found between the average salinity of the ice, as determined from its salinity profile, and the ice thickness at the profile location. Figure 8 plots the average salinity of the ice and the ice thickness as a function of position for profile B-B'. As the thickness of the ice increases, the average salinity decreases. To examine this relation further, the AIDJEX data were supplemented with salinity observations from sea ice of varying thickness and age collected at other arctic and subarctic locations. The investigators, number of cores, and sampling locations and dates are summarized in Table I. The average salinity/ice thickness data are tabulated in Appendix B. In the analysis, the data were divided into two sets based on the condition of the ice at the time of sampling. Figure 9 contains the results from cores collected from cold ice during the ice growth season. Figure 10 contains salinity samples taken only from warm, deteriorated ice during the melt season. In the cold ice (Fig. 9) there is a pronounced decrease in the mean ice salinity associated with an increase in the ice thickness, and a sharp break occurs in the curve at approximately 0.4 m. The relationship between $\overline{S}$ (the average salinity of the ice in ‰) and h (the ice thi ..ess in meters) can be well represented by two linear regression lines of $\overline{S}$ upon h:

$$\overline{S} = 14.24 - 19.39h \qquad h \leq 0.4 \text{ m}$$

$$\overline{S} = 7.88 - 1.59h \qquad h > 0.4 \text{ m}$$

The correlation coefficients for these relations are -0.78 and -0.94, respectively, significantly different from zero at the 0.005 level. Least-squares fits of the combined data by a polynomial and exponential curve were also made. However, because of the apparent sharp break in slope at 0.4 m significantly poorer fits were obtained.

The decrease in $\overline{S}$ with increasing h as shown in Figure 9 is hardly surprising, in first-year ice similar trends have been documented by Malmgren (1927) and by Weeks and Lee (1958, 1962).

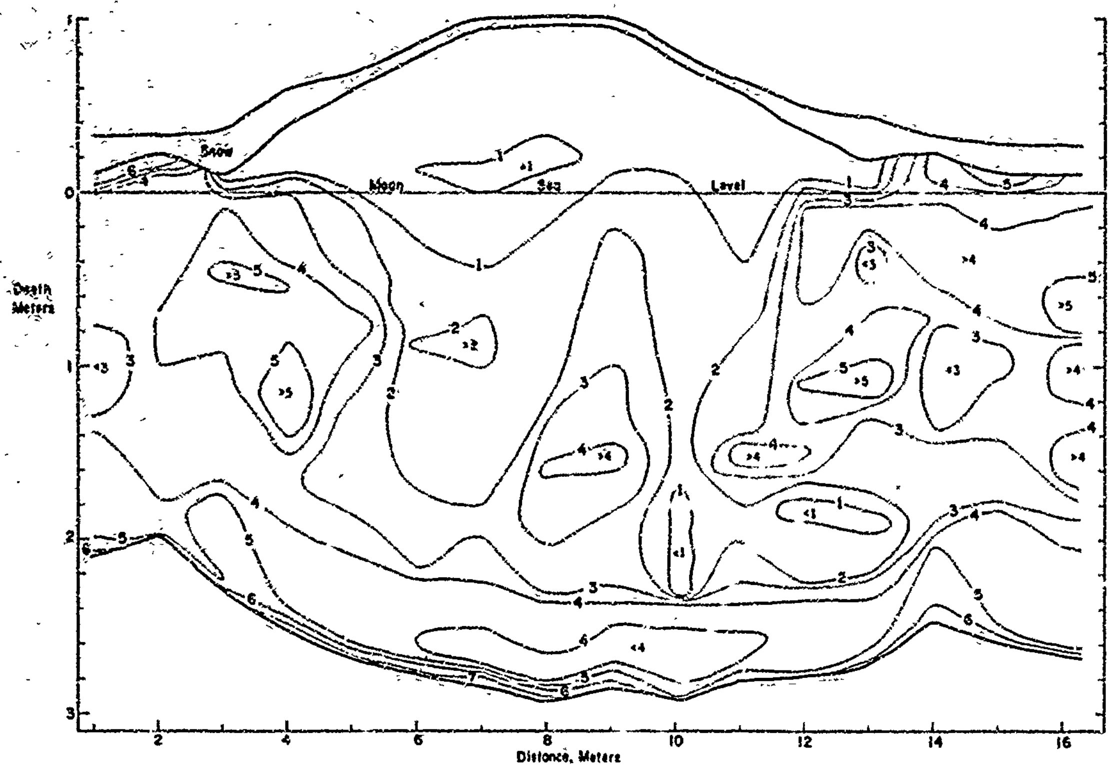

Figure 7. Cross section B-B' (Fig. 1) illustrating the variation of salinity with topography. Isosalinity lines are drawn at 1 ‰ intervals.

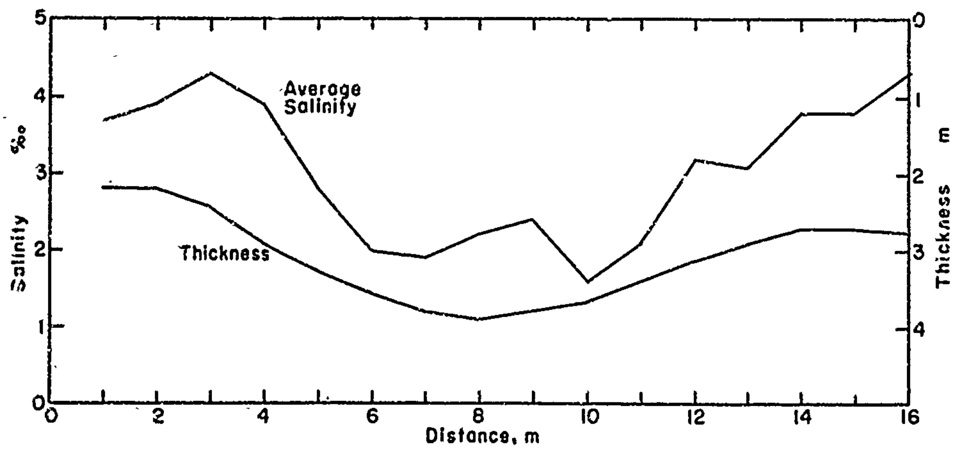

Figure 8. Average salinity of the ice and the ice thickness plotted as a function of position for profile B-B' (Fig. 1).

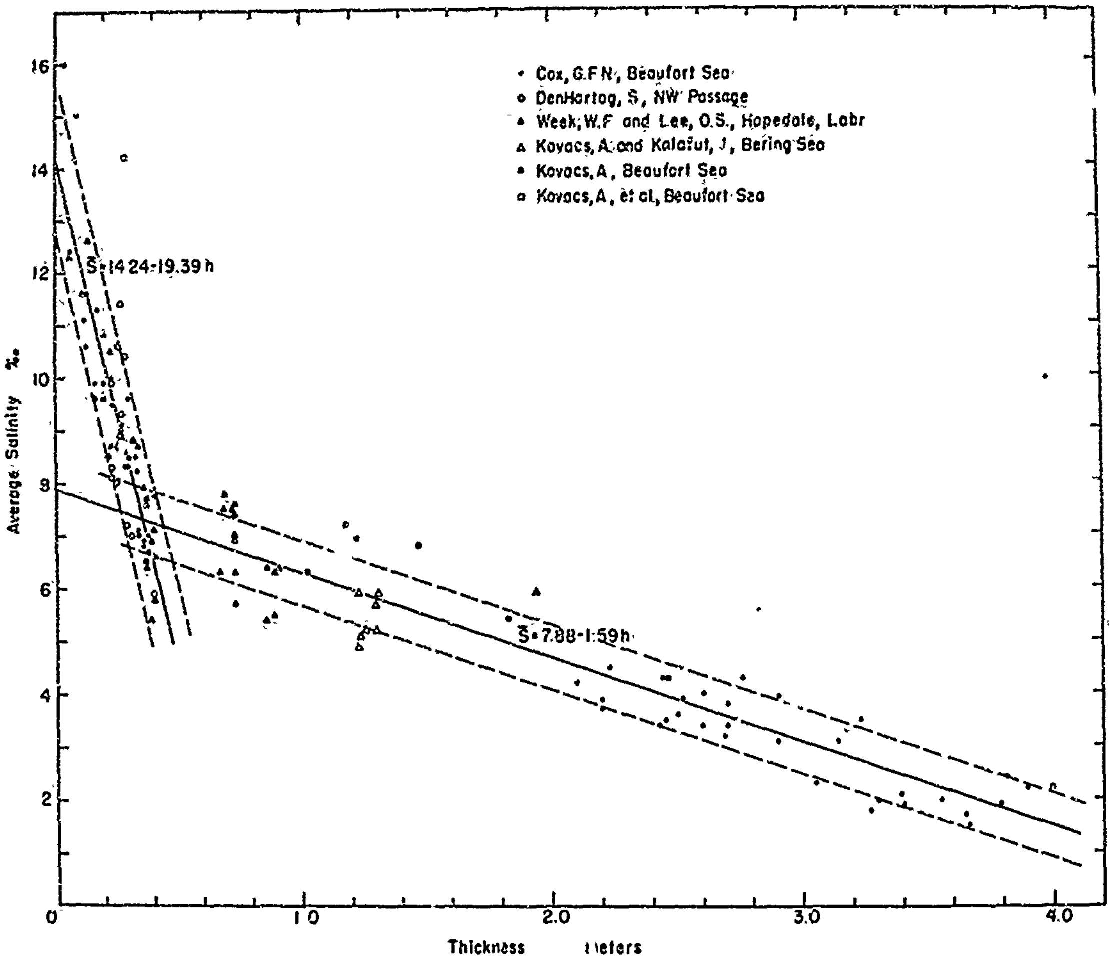

Figure 9. Average salinity of sea ice as a function of ice thickness for cold sea ice sampled during the growth season. The standard error of the estimate is 1.5 ‰ for thin ice and 0.6 ‰ for thick ice.

Table I. Data sources for average sea ice salinities (personal communications).

Location	*Ice type*	*Thickness (m)*	*Observation period*	*No. of cores*	*Source*
Cold ice < 0.4 m					
Hopedale, Labrador	Young	0.08-0.40	Dec-Jan 1957	25	Weeks and Lee
Viscount Melville Sound	Young	0.22-0.40	Oct 1969	14	DenHartog
Beaufort Sea	Young	0.03-0.40	Apr 1972	24	Cox
Cold ice > 0.4 m					
Hopedale, Labrador	First-year	0.68-0.92	Jan-Mar 1957	15	Weeks and Lee
Bering Sea	First-year	1.22-1.30	Feb-Mar 1970	9	Kovacs and Kalafut
Beaufort Sea	First-year	1.02-1.48	Apr 1969	4	Kovacs
	Multiyear	1.85-4.00	Mar 1971	3	Kovacs et al.
	Multiyear	2.10-3.90	Mar-Apr 1972	30	Cox
Warm ice					
Hopedale, Labrador	First-year	1.03-1.18	Mar-May 1957	14	Weeks and Lee
Beaufort Sea	Multiyear	2.64-3.60	June-Aug 1958	9	Assur
Viscount Melville Sound	Multiyear	0.88-3.88	Sept-Oct 1969	18	DenHartog

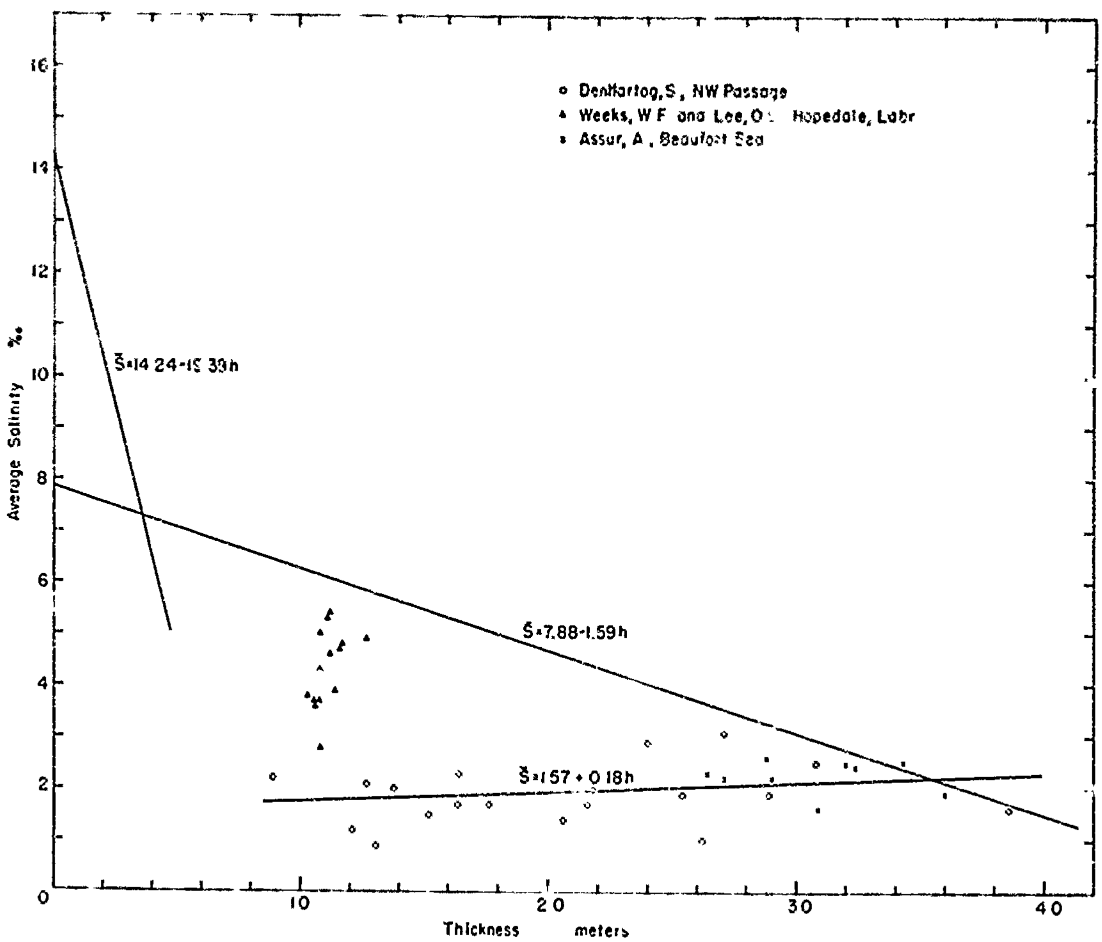

Figure 10. Average salinity of sea ice as a function of ice thickness for warm sea ice sampled during or at the end of the melt season.

However, the observation that the values from a wide variety of field sites lie on the same curve with very little scatter was unexpected, particularly for multiyear ice.

Figure 10 shows a plot of $\overline{S}$ versus h values obtained from sea ice that was nearly at melting temperature when sampled. Much of this ice showed signs of deterioration and contained large cavities and drainage tubes. Appreciable amounts of brine were probably lost during sampling. The data from Hopedale, Labrador, were collected in first-year ice at the start of the melt season. The remainder of the data came from multiyear ice in Viscount Melville Sound and the Beaufort Sea. A linear regression line of $\overline{S}$ upon h for these latter data gives

$$\overline{S} = 1.58 + 0.18h$$

with a correlation coefficient of +0.25, which is not significantly different from zero at the 0.10 level. The average salinity of the warm multiyear ice is clearly lower than the average observed for cold multiyear ice of a similar thickness.

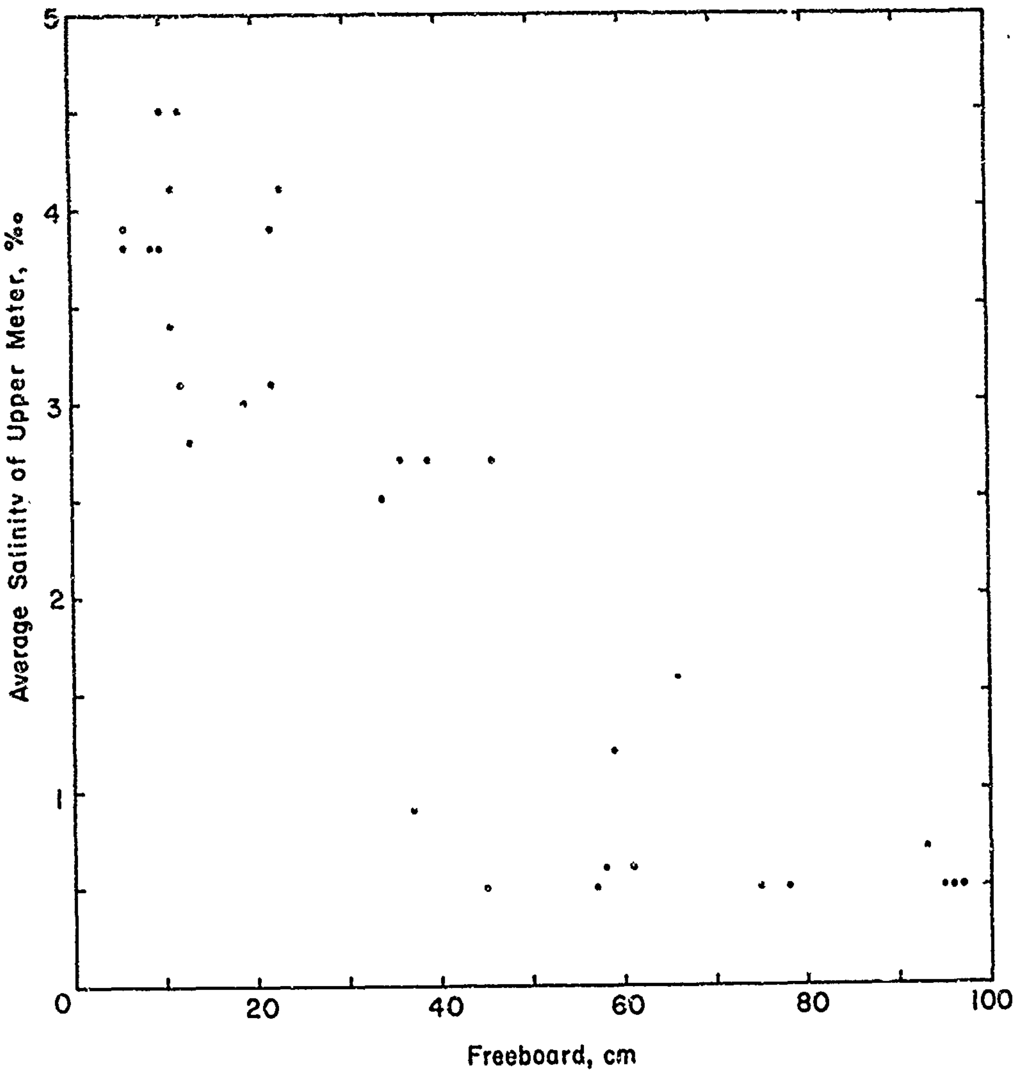

Figure 11. Plot of the average salinity of the upper meter of the ice versus the freeboard height.

DISCUSSION

The low salt content (less than 1 ‰) of the upper portions of the hummocks is probably due primarily to brine drainage by flushing. Flushing resembles gravity drainage in that the brine moves through interconnected tubes and cavities. The force to overcome capillary retention is the hydrostatic head produced when snow or ice melts on the surface. A hydrostatic head limits flushing to periods of melt and to locations in which the ice above the freeboard is permeable (Untersteiner 1967). If such a process is responsible for brine drainage, a strong relationship should be evident between the average salinity of the upper portion of the ice and the freeboard height. Most of the salinity profiles did show a gradual decrease in salinity above sea level (Fig. 2, 4), and those that did not (Fig. 3) had a very low freeboard. Figure 11 shows the average salinity of the upper meter of the ice plotted against the freeboard height. As the freeboard height increases, the average salinity of the upper portion of the ice decreases. The correlation coefficient for the data is -0.88, which is significantly different from zero at the 0.005 level.

Since the growth history of the ice sheet is unknown, the characteristics of the depression salinity profiles cannot be readily explained. The high average salinity and crude C shape of the depression profiles suggest that the ice beneath the depressions could be first-year. It is not uncommon to find first-year ice in excess of 2 m thick. For instance, Langleben (1970) found smooth first-year ice 2.4 m thick in Tanquary Fiord, Ellesmere Island. The average salinity of this ice was about 4 ‰, which corresponds to the mean salinity of the average depression profile. Thus, the depressions may be areas within the multiyear floe that melted through during the previous summer and then refroze in the fall. The ice in such a frozen melt hole could conceivably exhibit the characteristics of the depression salinity profiles.

However, we doubt that these depressions were once melt holes. Not only is a melt hole a much rarer feature than a melt pond, but if all the depressions had indeed perforated the floe, it probably would not have survived the summer. A visit to the camp in October 1972 showed that only surface ponds had formed in the summer, even though the floe was farther south than it had been in the summer of 1971. We therefore believe that the differences we have observed between multiyear salinity profiles are related to surface melt pond formation and not to perforation.

The principal brine drainage mechanisms in sea ice are brine expulsion, gravity drainage, and flushing (Untersteiner 1967, Lake and Lewis 1970). In Figure 9 it is possible that the change in slope of the mean salinity versus ice thickness curve at 0.4 m is a result of a change in the dominant brine drainage mechanism from brine expulsion to gravity drainage. Recent experimental work on NaCl ice by Cox and Weeks (in preparation) has shown that a pronounced decrease in the brine drainage rate occurs at an ice thickness of approximately 0.4 m. However, more salinity data would probably show that the change in slope is continuous as opposed to the break in slope suggested by Figure 9.

It is also interesting to speculate on the reason for the difference between the average salinity of the cold ice sampled during the growth season (Fig. 9) and that of the warm ice sampled during the melt season (Fig. 10). Not only does the warm multiyear ice have a lower mean salinity (~2.0 ‰, as compared to 3.0 ‰), it also shows a very slight increase in mean salinity with increasing ice thickness. This contrasts to a pronounced decrease in mean salinity over a similar range of ice thickness ($1.0 < h < 4.0$ m) for cold ice. Possibly an annual cyclic variation of the mean salinity exists for multiyear sea ice. At the end of the melt season, after a period of ice deterioration and considerable brine drainage, the mean salinity should reach a minimum, and at the end of the growth season, after a period of bottom accretion and the refreezing of brine drainage cavities, the mean salinity should reach a maximum. The extent of the variations would be a function of the ice thickness. For example, the thinner the multiyear ice is at the end of the summer, the thicker the growth increment will be the following winter. Since the new ice will be more saline than the ice surviving the melt season, as shown quite clearly in Figure 7, the average salinity will increase.

CONCLUSIONS

The salinity distribution in multiyear sea ice is dependent on the ice topography and cannot be represented by a single profile. Distinct differences were found between hummock profiles and depression profiles. If additional observations verify that the depression salinity profiles we observed are typical of areas beneath depressions, models which assume a single salinity distribution for multiyear sea ice will have to be modified. This is particularly true inasmuch as the average ice salinity profile determined by Schwarzacher appears to represent only the hummocks.

The general relation between ice thickness and mean salinity can serve as a check for numerical models that predict the time dependence of sea ice salinity profiles as a function of both salt entrapment and brine drainage. The relation should be useful in working out correction factors in certain remote-sensing applications in which the signature of the ice depends upon the mean brine volume. It should also be helpful in developing relations between the large-scale rheological response of an ice sheet and some measure of the mechanical properties of the ice being deformed. However, before any definitive conclusions can be made regarding the salinity distribution in multiyear sea ice, a much greater quantity of salinity data must be obtained, particularly from ice whose growth history is at least partially known. It will be easy to collect such data during the main AIDJEX experiment in 1975-76.

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APPENDIX A: TABULATION OF AIDJEX CORE DATA.

Z is the depth in cm, *S* is the salinity in ‰, and *T* is the temperature in °C. Temperature profiles recorded only for Profiles S1 through S5b.

Profile S1 (Hummock)

Z(cm)	S(‰)	Z(cm)	T(°C)
5	0	3	–25.5
15	0	15	–26.2
25	0.1	22	–25.5
35	0.4	40	–23.8
45	0.4	50	–22.7
55	0.7	60	–22.8
65	0.6	70	–21.3
75	0.5	80	–20.9
85	0.8	100	–20.0
95	1.1	115	–18.6
105	0.9	125	–18.2
115	1.3	135	–17.4
125	1.9	140	–17.6
135	1.5	150	–16.1
145	1.6	160	–15.1
155	1.5	170	–14.4
165	1.7	180	–14.5
175	1.3	195	–12.8
185	1.7	205	–12.6
195	1.3	215	–12.6
205	1.3	230	–10.0
215	2.0	240	– 8.8
225	2.8	250	– 9.4
235	3.3	260	– 6.2
245	3.0	300	– 3.5
255	2.9	320	– 1.7
265	4.9		
275	3.5		
285	3.9		
295	4.5		
305	4.1		
315	5.0		
325	4.9		

Average salinity: 2.0 ‰
Ice thickness: 330 cm
Freeboard: 57 cm

Profile S2 (Depression)

Z(cm)	S(‰)	Z(cm)	T(°C)
5	2.1	3	–25.0
15	4.3	15	–23.2
25	4.5	25	–22.1
35	3.9	30	–22.1
45	3.6	40	–21.7
55	3.1	50	–20.2
65	2.1	60	–20.0
75	1.4	75	–19.0
85	1.3	85	–17.7

Profile S2 (Cont'd)

Z(cm)	S(‰)	Z(cm)	T(°C)
95	1.5	100	–16.4
105	5.0	105	–16.1
115	3.5	115	–14.7
125	2.5	125	–13.7
135	1.9	135	–13.5
145	1.9	165	–10.0
155	3.3	185	– 8.0
165	4.5	200	– 6.6
175	4.4	210	– 4.4
185	[illegible]	220	– 2.8
195	4.5	235	– 1.8
[illegible]	4.7		
[illegible]	3.8		
225	4.1		
235	4.5		

Average salinity: 3.4 ‰
Ice thickness: 243 cm
Freeboard: 13 cm

Profile S3 (Hummock)

Z(cm)	S(‰)	Z(cm)	T(°C)
5	0	20	–26.4
15	0.1	25	–26.0
25	0.3	40	–25.0
35	0.7	50	–24.9
45	0.9	60	–23.6
55	1.2	70	–22.6
65	1.5	85	–21.7
75	0.4	110	–20.0
85	0.3	120	–20.0
95	1.2	125	–20.5
105	1.6	140	–19.2
115	1.9	150	–19.8
125	1.6	170	–18.0
135	1.2	190	–16.0
145	1.3	210	–12.9
155	1.3	220	–12.2
165	1.2	250	–11.9
175	1.1	260	–11.0
185	1.3	280	– 8.5
195	1.7	305	– 4.3
205	1.7	325	– 7.5
215	1.5	336	– 3.3
225	1.1	353	– 1.8
235	1.1		
245	1.6		
255	1.5		

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Profile S3 (Cont'd)

Z(cm)	S(‰)	Z(cm)	T(°C)
265	1.7		
275	1.8		
285	1.8		
295	1.1		
305	3.0		
315	3.6		
325	2.9		
335	4.3		
345	3.9		
355	3.7		
363	3.9		

Average salinity: 1.7 ‰
Ice thickness: 365 cm
Freeboard: 93 cm

Profile S4 (Depression)

Z(cm)	S(‰)	Z(cm)	T(°C)
5	6.3	5	–19.3
15	3.3	15	–19.3
25	3.7	30	–18.1
35	3.9	40	–17.7
45	5.3	50	–17.2
55	4.6	70	–16.[illegible]
65	4.2	110	–12.6
75	4.6	120	–13.4
85	4.9	140	–10.4
95	5.9	160	– 7.6
105	4.4	180	– 5.5
115	3.3	200	– 4.1
125	2.8		
135	2.2		
145	2.8		
155	3.8		
165	5.2		
175	4.3		
185	4.1		
195	4.3		
205	4.4		

Average salinity: 4.2 ‰
Ice thickness: Lost lower segment of core
Freeboard: Not recorded

Profile S5a (Depression)

Z(cm)	S(‰)	Z(cm)	T(°C)
5	3.5	10	–20.2
15	3.8	30	–18.4
25	3.7	50	–17.6
35	4.0	70	–15.5
45	4.1	90	–14.3
55	3.7	120	–12.1
65	3.6	140	–10.0

Profile S5a (Cont'd)

Z(cm)	S(‰)	Z(cm)	T(°C)
75	3.0	170	– 9.6
85	3.8	190	– 7.1
95	3.7	225	– 3.5
105	4.9	240	– 2.5
115	5.9	253	– 1.8
125	6.0		
135	5.7		
145	4.9		
155	3.1		
165	1.5		
175	1.2		
185	1.3		
195	1.7		
205	3.6		
215	4.4		
225	5.3		
235	4.8		
245	4.8		
255	7.2		

Average salinity: 4.0 ‰
Ice thickness: 260 cm
Freeboard: 6 cm

Profile S5b (Depression)

Z(cm)	S(‰)	Z(cm)	T(°C)
5	4.4	10	–20.2
15	3.4	30	–18.4
25	4.2	50	–17.6
35	4.6	70	–15.5
45	4.1	90	–14.3
55	4.1	120	–12.1
65	4.1	140	–10.0
75	3.9	170	– 9.6
85	3.2	190	– 7.1
95	3.1	225	– 3.5
105	2.8	240	– 2.5
115	2.9	253	– 1.8
125	2.2		
135	3.1		
145	2.8		
155	1.7		
165	1.1		
175	1.1		
185	1.5		
195	3.4		
205	4.3		
215	4.4		
225	4.5		
235	4.3		
245	4.2		
255	4.8		

Average salinity: 3.4 ‰
Ice thickness: 260 cm
Freeboard: 6 cm

Profile S6 (Hummock)

Z(cm)	S(‰)
5	0
15	0.1
25	0.2
35	0.3
45	1.8
55	1.0
65	0.9
75	1.0
85	1.5
95	2.1
105	2.8
115	3.1
125	1.9
135	1.8
145	2.0
155	2.2
165	3.3
175	3.7
185	2.9
195	2.5
205	3.3
215	3.7
225	2.4
235	3.2
245	3.5
255	3.6
265	4.3
273	4.5

Avg salinity: 2.3 ‰
Ice thickness: Lost lower segment of core
Freeboard: 37 cm

Profile S7 (Depression)

Z(cm)	S(‰)
5	5.0
15	4.6
25	3.8
35	4.4
45	3.1
55	3.6
65	2.6
75	3.7
85	3.8
95	2.9
105	2.6
115	3.5
125	3.0
135	2.5
145	1.9
155	1.5
165	1.6

Profile S7 (Cont'd)

Z(cm)	S(‰)
175	3.2
185	5.3
195	5.0
205	4.7
215	4.5
225	4.4
235	4.4
245	5.2

Avg salinity: 3.6 ‰
Ice thickness: 250 cm
Freeboard: 9 cm

Profile S8 (Hummock)

Z(cm)	S(‰)
5	0
15	0
25	0.2
35	0.3
45	0.3
55	0.3
65	0.8
75	1.2
85	0.8
95	0.9
105	0.9
115	1.0
125	0.9
135	1.3
145	1.1
155	1.0
165	1.1
175	1.2
185	1.7
195	2.1
205	2.5
215	2.3
225	2.2
235	2.0
245	2.2
255	2.4
265	3.2
275	3.4
285	3.6
295	4.8
305	5.0
315	4.3
325	3.9
335	4.4

Avg salinity: 1.9 ‰
Ice thickness: 340 cm
Freeboard: 45 cm

Profile S9 (Depression)

Z(cm)	S(‰)
5	0.5
15	4.0
25	3.9
35	4.3
45	5.4
55	5.5
65	5.1
75	5.7
85	5.0
95	6.0
105	4.2
115	3.3
125	3.2
135	4.0
145	2.9
155	2.7
165	1.7
175	4.4
185	3.4
195	2.7
205	1.7
215	1.8
225	1.3
235	1.4
245	2.3
255	2.1
265	3.9
275	4.4
285	4.7
295	4.7
305	4.7
317	5.4

Avg salinity: 3.5 ‰
Ice thickness. 323 cm
Freeboard: 12 cm

Profile S10 (Hummock)

Z(cm)	S(‰)
5	0.1
15	0.2
25	0.7
35	1.2
45	2.1
55	3.8
65	4.7
75	5.1
85	4.5
95	2.5
105	2.7
115	3.4
125	3.6
135	3.3
145	4.0

Profile S10 (Cont'd)

Z(cm)	S(‰)
155	3.8
165	4.1
175	4.5
185	4.2
195	4.4
205	4.4
215	4.0
225	4.4
235	4.4
243	3.4

Avg salinity: 3.5 ‰
Ice thickness: 245 cm
Freeboard: 34 cm

Profile S11 (Hummock)

Z(cm)	S(‰)
5	0
15	0.2
25	0.6
35	1.2
45	2.9
55	3.5
65	4.3
75	4.0
85	5.7
95	4.3
105	3.4
115	2.5
125	1.7
135	1.5
145	1.6
155	2.5
165	2.5
175	2.3
185	2.7
195	3.2
205	3.9
215	4.5
225	5.7
235	5.1
245	4.5
255	5.2
265	6.5

Avg salinity: 3.2 ‰
Ice thickness: 269 cm
Freeboard: 46 cm

Profile S12 (Depression)

Z(cm)	S(‰)
5	0
15	0.8
25	4.1
35	4.2
45	3.6
55	5.5
65	3.7
75	2.7
85	2.9
95	3.1
105	5.3
115	5.3
125	4.7
135	5.2
145	3.6
155	3.7
165	3.9
175	4.2
185	4.4
195	4.6
205	4.5
215	4.2
225	4.0
235	5.0
246	5.3

Avg salinity: 3.9 ‰
Ice thickness: 252 cm
Freeboard: 22 cm

Profile S13 (Depression)

Z(cm)	S(‰)
5	5.2
15	3.2
25	4.6
35	4.5
45	4.0
55	4.7
65	4.2
75	4.3
85	3.7
95	3.8
105	3.5
115	2.6
125	3.0
135	3.6
145	5.0
155	4.9
165	5.1
175	5.5
185	5.4
195	5.8
205	5.2
215	5.2
222	7.5

Avg salinity: 4.5 ‰
Ice thickness: 223 cm
Freeboard: 12 cm

Profile S14 (Hummock)

Z(cm)	S(‰)
5	0
15	0
25	0.1
35	0.3
45	0.5
55	0.9
65	0.8
75	0.8
85	1.0
95	1.4
105	1.4
115	1.4
125	1.4
135	2.0
145	2.4
155	2.2
165	1.9
175	1.6
185	2.3
195	3.0
205	2.9
215	2.8
225	2.3
235	3.1
245	4.0
255	4.0
265	4.0
275	4.3
285	4.1
295	3.7
303	9.5

Avg salinity: 2.3 ‰
Ice thickness: 305 cm
Freeboard: 61 cm

Profile D1 (Depression)

Z(cm)	S(‰)
5	6.7
15	3.1
25	2.8
35	3.8
45	3.1
55	2.9
65	3.0
75	3.1
85	3.1
95	2.7
105	2.3
115	2.8
125	2.7
135	2.5
145	3.3
155	4.5
165	4.5
175	4.7
185	4.5

Profile D1 (Cont'd)

Z(cm)	S(‰)
195	4.5
205	4.1
215	5.5

Avg salinity: 3.7 ‰
Ice thickness: 220 cm
Freeboard: 11 cm

Profile D2

Z(cm)	S(‰)
5	6.5
15	2.9
25	3.7
35	3.5
45	3.6
55	3.3
65	3.8
75	3.7
85	3.9
95	4.2
105	3.9
115	4.4
125	3.9
135	3.2
145	2.5
155	3.8
165	4.5
175	3.9
185	3.5
195	3.7
205	4.3
215	4.2

Avg salinity: 3.9 ‰
Ice thickness: 220 cm
Freeboard: 22 cm

Profile D3

Z(cm)	S(‰)
5	1.5
15	3.2
25	4.6
35	4.1
45	4.7
55	5.3
65	4.9
75	4.2
85	4.3
95	4.5
105	3.9
115	3.0
125	4.4
135	3.5
145	3.1

Profile D3 (Cont'd)

Z(cm)	S(‰)
155	3.1
165	3.7
175	3.3
185	5.0
195	5.1
205	5.0
215	4.3
225	5.1
235	4.8
242	9.0

Avg salinity: 4.3 ‰
Ice thickness: 244 cm
Freeboard: 10 cm

Profile D4

Z(cm)	S(‰)
5	0
15	0.2
25	0.6
35	2.1
45	3.9
55	4.1
65	3.2
75	3.3
85	4.2
95	5.0
105	4.5
115	4.5
125	5.0
135	5.2
145	5.1
155	5.5
165	5.7
175	5.7
185	4.3
195	3.2
205	3.0
215	3.0
225	3.5
235	4.3
245	4.3
255	4.5
265	4.6
275	4.4
285	6.5

Avg salinity: 3.9 ‰
Ice thickness: 290 cm
Freeboard: 39 cm

Profile D5

Z(cm)	S(‰)
5	0.1
15	0.1
25	0.3
35	0.5
45	0.6
55	0.8
65	1.4
75	3.7
85	1.7
95	2.5
105	2.5
115	3.6
125	3.1
135	4.5
145	4.7
155	3.1
165	2.7
175	3.1
185	2.3
195	2.1
205	2.1
215	2.4
225	2.0
235	2.6
245	3.2
255	3.5
265	3.5
275	5.1
285	4.9
295	4.8
305	4.7
315	4.5
324	6.6

Avg salinity: 2.8 ‰
Ice thickness: 327 cm
Freeboard: 59 cm

Profile D6

Z(cm)	S(‰)
5	0
15	0
25	0.1
35	0.2
45	0.3
55	0.6
65	1.0
75	0.7
85	0.9
95	0.9
105	1.0
115	1.2
125	1.3
135	1.1

Profile D6 (Cont'd)

Z(cm)	S(‰)
145	1.0
155	1.4
165	2.1
175	1.9
185	1.9
195	1.9
205	1.7
215	1.7
225	1.9
235	2.1
245	1.9
255	2.1
265	2.4
275	2.5
285	2.6
295	3.1
305	4.9
315	4.9
325	4.2
335	4.0
345	4.1
353	8.5

Avg salinity: 2.0 ‰
Ice thickness: 335 cm
Freeboard: 78 cm

Profile D7

Z(cm)	S(‰)
5	0
15	0
25	0.1
35	0.2
45	0.3
55	0.4
65	0.7
75	0.7
85	1.5
95	1.0
105	0.5
115	0.5
125	0.7
135	0.9
145	1.2
155	1.7
165	2.0
175	2.1
185	2.3
195	2.0
205	1.8
215	1.9
225	1.7
235	1.4
245	1.4

Profile D7 (Cont'd)

Z(cm)	S(‰)
255	1.7
265	1.8
275	2.0
285	2.5
295	3.1
305	3.3
315	3.9
325	4.2
335	4.3
345	4.0
355	3.5
365	3.6
375	7.7

Avg salinity: 1.9 ‰
Ice thickness: 379 cm
Freeboard: 95 cm

Profile D8 (Hummock)

Z(cm)	S(‰)
5	0
15	0
25	0.1
35	0.1
45	0.2
55	0.4
65	1.1
75	1.9
85	1.0
95	0.6
105	0.3
115	0.8
125	1.8
135	1.6
145	1.9
155	1.5
165	1.2
175	1.3
185	1.5
195	1.3
205	1.9
215	2.3
225	3.0
235	2.9
245	3.5
255	4.2
265	3.7
275	3.7
285	3.7
295	3.4
305	2.2
315	2.2
325	2.8
335	4.5

Profile D8 (Cont'd)

Z(cm)	S(‰)
345	4.9
355	4.6
365	3.8
375	3.3
385	6.4

Avg salinity: 2.2 ‰
Ice thickness: 389 cm
Freeboard: 97 cm

Profile D9

Z(cm)	S(‰)
5	0
15	0
25	0.1
35	0.3
45	0.4
55	0.5
65	0.6
75	0.7
85	1.0
95	1.1
105	1.3
115	1.8
125	2.7
135	2.1
145	1.7
155	2.2
165	2.8
175	2.6
185	2.8
195	3.0
205	3.0
215	3.3
225	3.4
235	3.4
245	4.2
255	4.0
265	3.6
275	3.1
285	2.5
295	2.2
305	2.0
315	2.5
325	3.4
335	4.4
345	4.0
355	3.7
365	3.9
376	5.9

Avg salinity: 2.4 ‰
Ice thickness: 381 cm
Freeboard: 96 cm

Profile D10

Z(cm)	S(‰)
5	0
15	0
25	0.1
35	0.1
45	0.2
55	0.7
65	1.0
75	1.0
85	1.1
95	1.1
105	1.1
115	1.2
125	1.3
135	1.6
145	1.2
155	1.4
165	1.5
175	1.8
185	1.8
195	1.7
205	1.1
215	1.9
225	2.1
235	1.7
245	1.0
255	0.9
265	1.0
275	0.8
285	0.8
295	0.9
305	0.9
315	4.1
325	4.0
335	4.2
345	3.9
355	3.7
363	4.6

Avg salinity: 1.6 ‰
Ice thickness: 366 cm
Freeboard: 75 cm

Profile D11

Z(cm)	S(‰)
5	0.1
15	0.1
25	0.2
35	0.4
45	0.5
55	0.6
65	0.8
75	0.9
85	1.0
95	0.9

Profile D11 (Cont'd)

Z(cm)	S(‰)
105	1.2
115	1.4
125	1.5
135	1.8
145	2.2
155	2.1
165	2.3
175	2.1
185	2.7
195	2.8
205	4.7
215	4.0
225	2.2
235	2.1
245	1.8
255	1.5
265	2.2
275	2.1
285	3.5
295	4.0
305	4.1
315	3.9
325	3.7
335	5.6

Avg salinity: 2.1 ‰
Ice thickness: 339 cm
Freeboard: 58 cm

Profile D12

Z(cm)	S(‰)
5	0.1
15	0.1
25	0.5
35	2.2
45	4.0
55	3.9
65	4.1
75	3.6
85	4.1
95	4.3
105	3.3
115	3.7
125	3.5
135	3.3
145	5.4
155	4.4
165	4.8
175	3.3
185	4.2
195	3.5
205	1.7
215	0.7
225	1.0

Profile D12 (Cont'd)

Z(cm)	S(‰)
235	1.3
245	1.1
255	0.9
265	3.2
275	4.8
285	4.4
295	4.2
305	4.5
312	3.8

Avg salinity: 3.2 ‰
Ice thickness: 314 cm
Freeboard: 36 cm

Profile D13

Z(cm)	S(‰)
5	0.1
15	0.7
25	3.9
35	4.5
45	3.6
55	2.7
65	2.7
75	3.2
85	3.6
95	4.6
105	4.0
115	5.0
125	5.5
135	5.5
145	3.7
155	2.1
165	2.1
175	2.3
185	2.7
195	1.3
205	0.9
215	1.0
225	1.2
235	1.3
245	3.5
255	4.1
265	4.3
275	4.2
285	5.7

Avg salinity: 3.1 ‰
Ice thickness: 290 cm
Freeboard: 19 cm

Profile D14

Z(cm)	S(‰)
5	4.7
15	4.1
25	3.4
35	4.8
45	4.6
55	4.1
65	4.3
75	4.1
85	3.6
95	3.9
105	2.7
115	2.8
125	2.8
135	2.1
145	2.5
155	2.3
165	3.9
175	2.5
185	2.5
195	2.4
205	2.7
215	3.1
225	4.7
235	5.7
245	5.7
255	5.3
265	6.8

Avg salinity: 3.8 ‰
Ice thickness: 270 cm
Freeboard: 23 cm

Profile D15

Z(cm)	S(‰)
5	5.7
15	3.3
25	3.2
35	4.1
45	4.7
55	4.1
65	4.0
75	4.1
85	4.0
95	3.5
105	2.3
115	2.7
125	3.5
135	3.4
145	3.4
155	2.9
165	2.8
175	2.7
185	2.9
195	4.1

Profile D15 (Cont'd)

Z(cm)	S(‰)
205	4.1
215	4.1
225	4.1
235	4.5
245	4.9
255	4.5
265	6.0

Avg salinity: 3.8 ‰
Ice thickness: 270 cm
Freeboard: 11 cm

Profile D16 (Depression)

Z(cm)	S(‰)
5	3.8
15	3.3
25	4.3
35	3.9
45	4.5
55	4.5
65	5.7
75	5.6
85	5.4
95	3.8
105	4.5
115	4.8
125	4.5
135	3.1
145	3.5
155	4.5
165	4.8
175	4.2
185	2.6
195	2.9
205	3.5
215	4.1
225	4.2
235	4.4
245	4.3
255	4.2
265	4.2
273	5.9

Avg salinity: 4.3 ‰
Ice thickness: 276 cm
Freeboard: 10 cm

h is the thickness in m and $\bar{S}$ is the average salinity in ‰.

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Multiyear ice

h(m)	$\bar{S}$(‰)
3.30	2.0
2.43	3.4
3.65	1.7
2.10	4.2
2.60	4.0
2.50	3.6
2.50	3.4
3.40	1.9
3.23	3.5
2.69	3.2
2.52	3.9
2.45	3.5
2.23	4.5
3.05	2.3
2.20	3.7
2.20	3.9
2.44	4.3
2.90	3.9
3.27	2.8
3.55	2.0
3.79	1.9
3.89	2.2
3.81	2.4
3.66	1.6
3.39	2.1
3.14	3.2
2.90	3.1
2.70	3.4
2.70	3.8
2.76	4.3

New ice

0.035	16.0
0.065	12.4
0.095	15.0
0.125	11.1
0.130	11.6
0.130	10.6
0.175	11.3
0.165	9.9
0.200	9.9
0.200	10.2
0.235	9.5
0.230	10.0
0.27	9.1
0.27	9.0
0.30	9.6
0.30	8.5

Cox (Cont'd)

h(m)	$\bar{S}$(‰)
0.33	8.5
0.33	8.2
0.34	7.1
0.34	7.0
0.36	6.8
0.36	6.9
0.38	7.0
0.38	6.7

W.F. Weeks and O.S. Lee, Hopedale, Lab.

New ice

h(m)	$\bar{S}$(‰)
0.12	11.6
0.17	9.6
0.22	8.5
0.29	8.3
0.37	6.4
0.39	5.4
0.12	16.8
0.14	12.6
0.20	10.8
0.20	9.6
0.23	10.5
0.06	12.3
0.23	8.7
0.29	8.3
0.32	8.8
0.34	8.7
0.36	7.9
0.37	7.6
0.37	7.7
0.37	6.5
0.40	7.2
0.40	6.6
0.40	5.8
0.39	6.9

Young ice covered by infiltrated snow ice

0.69	7.8
0.72	7.5
0.67	6.3
0.67	7.5
0.73	7.0
0.73	7.4
0.73	6.3

Weeks and Lee (Cont'd)

h(m)	$\bar{S}$(‰)
0.73	7.6
0.86	6.4
0.86	5.4
0.89	5.5
0.89	6.3
0.73	5.7
0.73	6.9
0.91	6.4

Young ice exhibiting rapid deterioration

0.83	3.8
0.88	2.8
0.86	3.7
0.86	3.6
0.88	4.3
0.88	5.0
0.94	3.9
0.87	3.7
0.92	4.6
0.92	5.4
0.97	4.8
1.07	4.9
0.96	4.7
0.91	5.3

A. Kovacs, Beaufort Sea.

h(m)	$\bar{S}$(‰)
1.22	6.9
1.02	6.3
1.47	6.8
1.18	7.2

A. Kovacs; W.F. Weeks; S. Ackley and W.D. Hibler, III.

h(m)	$\bar{S}$(‰)
3.99	2.2
2.46	4.3
1.83	5.4

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22 A. Kovacs and J. Kalafut, Bering Sea.

h(m)	$\overline{S}$(‰)
1.94	5.9
1.24	5.1
1.23	4.9
1.26	5.2
1.26	5.2
1.30	5.7
1.31	5.9
1.30	5.2
1.33	5.9

A. Assur, Beaufort Sea.

h(m)	$\overline{S}$(‰)
3.60	1.9
3.20	2.5
2.88	2.6
2.71	2.2
3.43	2.5
3.10	1.6
2.90	2.2
2.64	2.3
3.24	2.4

S. DenHartog, N.W. Passage.

New ice

h(m)	$\overline{S}$(‰)
0.20	5.9
0.27	8.8
0.26	8.7
0.27	7.2
0.26	10.6
0.25	8.0
0.23	8.1
0.23	8.3
0.31	7.0
0.23	9.9
0.27	11.4
0.29	14.2
0.29	10.4
0.27	9.3
0.27	8.9

Young to multiyear ice exhibiting much deterioration

2.54	1.9
1.76	1.7
2.06	1.4
1.21	1.2
2.52	1.5

DenHartog (Cont'd)

h(m)	$\overline{S}$(‰)
3.03	2.5
2.16	1.7
1.64	1.7
1.31	0.9
2.80	1.9
2.40	2.9
0.89	2.2
1.64	2.3
2.71	3.1
1.32	2.0
1.27	2.1
3.86	1.6
2.18	2.0
2.28	2.5
2.16	2.0
2.62	1.0